Interdigitated micro array electrodes with standing nanostructures for micro channel electrochemical biosensors

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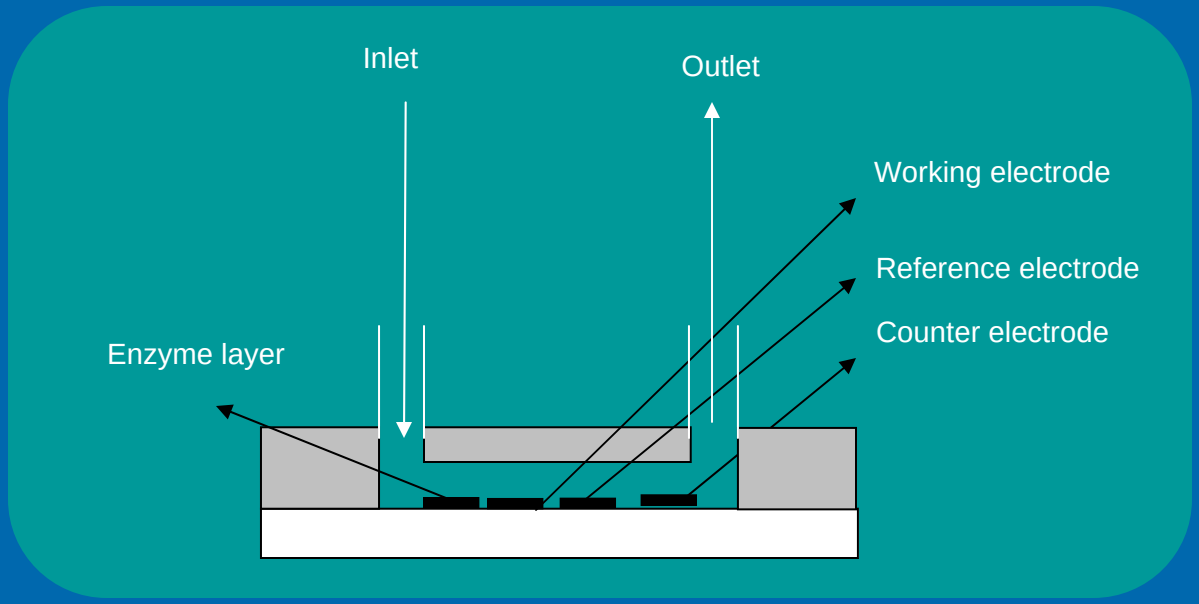
Introduction

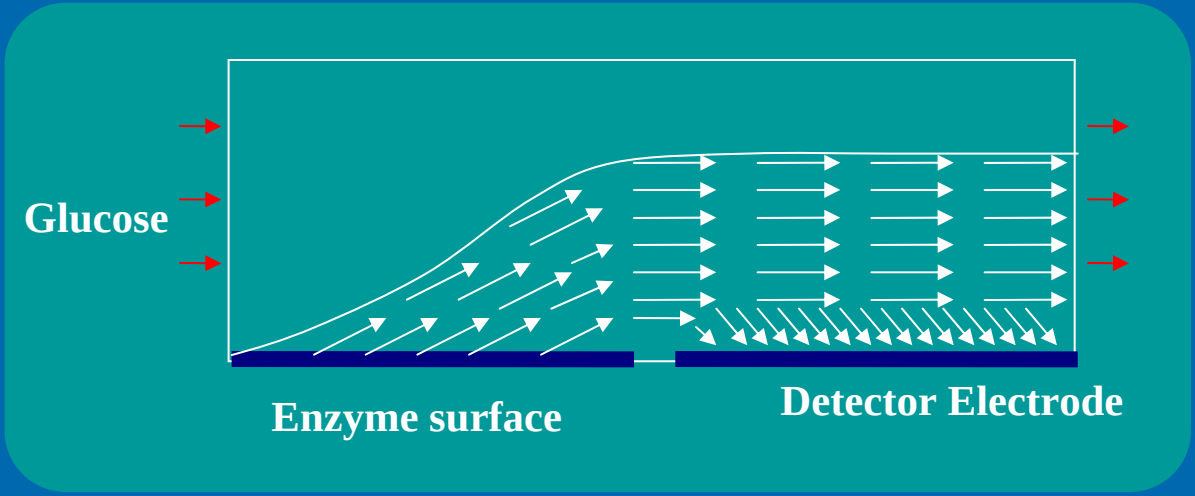
- **Diabetes**
  - A disease in which body does not use or make insulin
  - 170 million people have been affected
  - Complications include heart disease, blindness, nerve damage, kidney disease
- **Glucose Monitoring**
  - Monitor blood glucose level
  - Avoid diabetes related complications
  - Help in understanding the factors (food and activities) that affect the blood glucose level
- **Real-time continuous monitoring**
  - Hypoglycemia, Hyperglycemia - large fluctuations in glucose level
  - Better manage the glucose level (Trend over a time period)

Conventional Micro Flow Channel Biosensor



- Biosensors coupled with micro flow channel- Third generation
- Enzyme layer is placed at the upstream of the glucose flow
- **Applications** – L-glutamate, lactate, glucose, choline, catecholamine
- **Advantages** - Continuous measurement, Reduced sample volume, Low detection limit, Good reproducibility, low cost

Issues with Micro Flow Channel Biosensor



- **Poor current response-**

  Low Collection Efficiency

  - Ratio of the amount product detected at the working electrode to the amount of product produced at the enzyme electrode

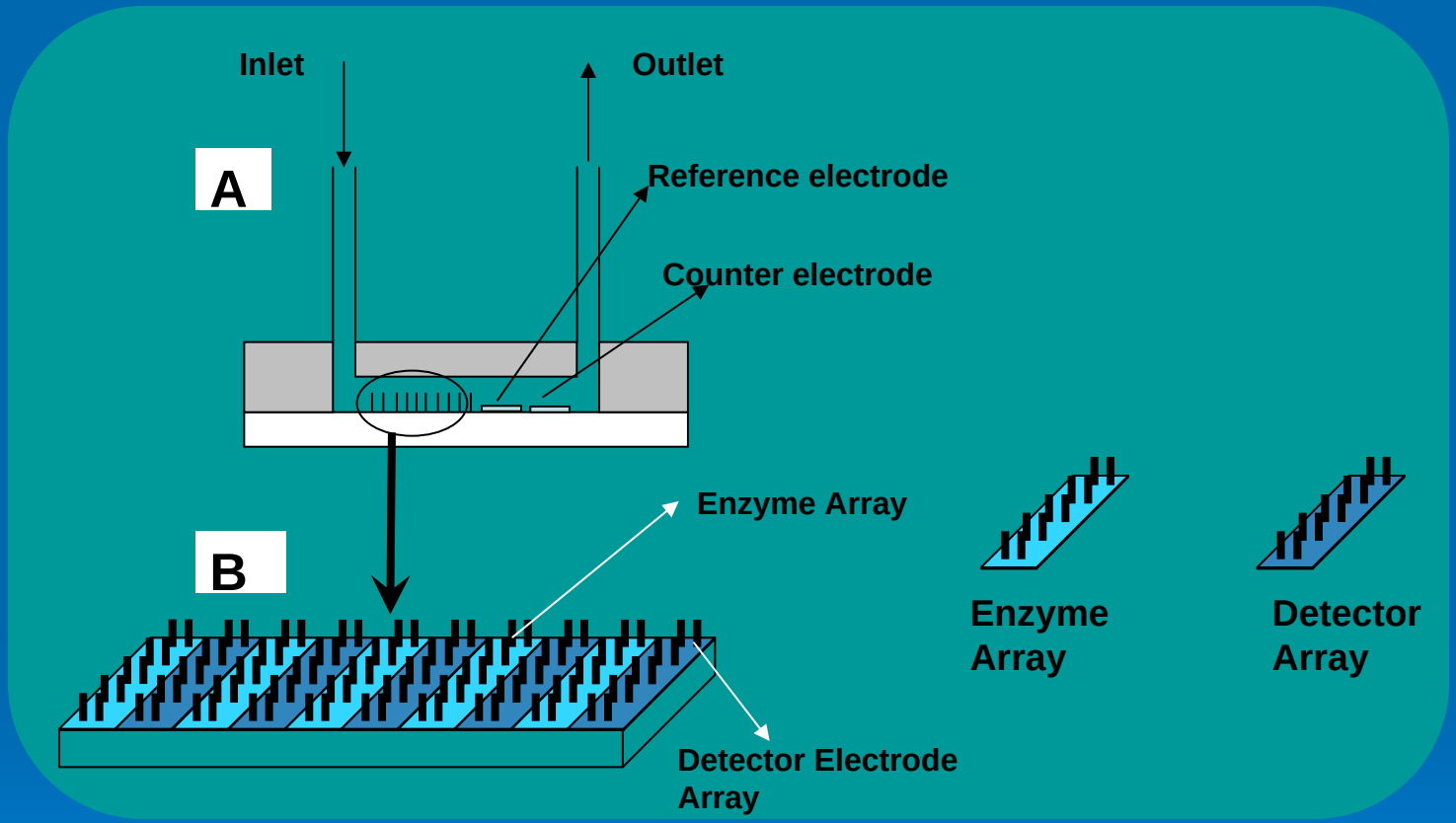
  Low Conversion Efficiency

  - Ratio of the amount of the hydrogen peroxide oxidized at the detector electrode to the amount of glucose passed through the cross section normal to the flow

Objective

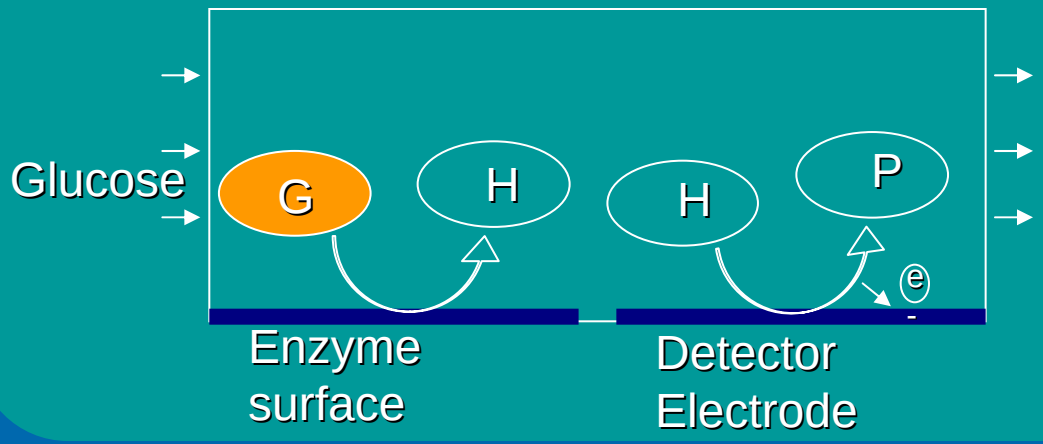
- To develop and optimize a new electrode design that can provide maximum current response.

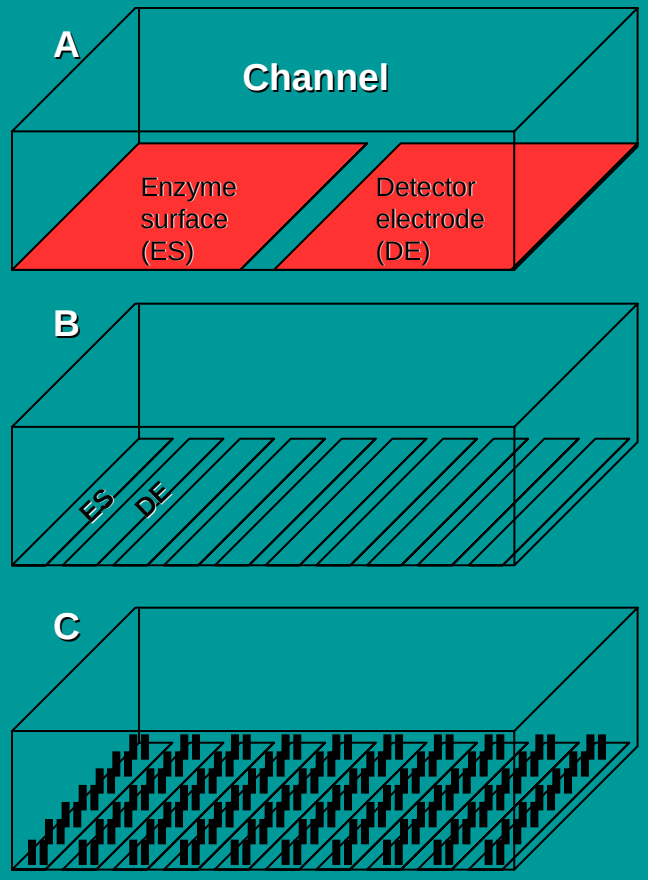
Device Proposed



- Interdigitated micro array - To increase the collection efficiency
- Nanopillar array – To increase the conversion efficiency

Model Development





H-Hydrogen Peroxide

P-Product formed during oxidation of Hydrogen Peroxide

- Three different designs were considered
- A model is developed using COMSOL Multiphysics to simulate the performance of the amperometric microchannel biosensor

Model Development

➢Navier-Stokes Equation

$$\nabla \cdot \eta(\nabla u + (\nabla u)^T) + \rho(u \cdot \nabla)u + \nabla p = F$$

$$\nabla \cdot u = 0$$

➢Convection and Diffusion Equation

$$D_i \nabla C_i + C_i u = N_i$$

$$N = \frac{V_{\max}[S]}{K_m + [S]}$$

N denotes the flux, C_i denotes the concentration, *D* denotes it diffusion coefficient of the species i, *u* denotes the velocity.

Boundary Conditions

- At the enzyme surface

$$N_{Glucose} = N_{H_2O_2}$$

- At Working electrode

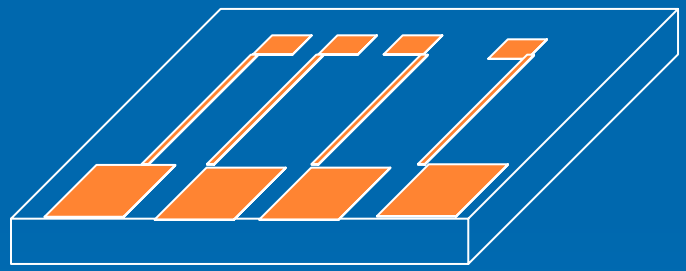
$$C_{H_2O_2} = 0$$

- No slip is assumed at the channel walls

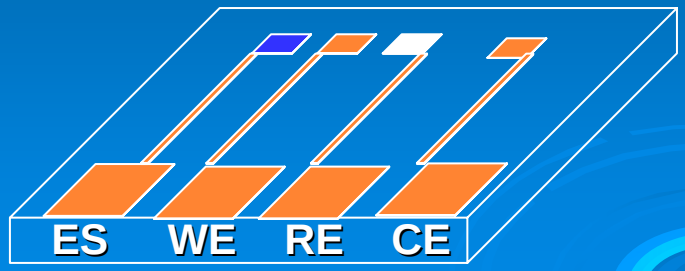
$$u = 0$$

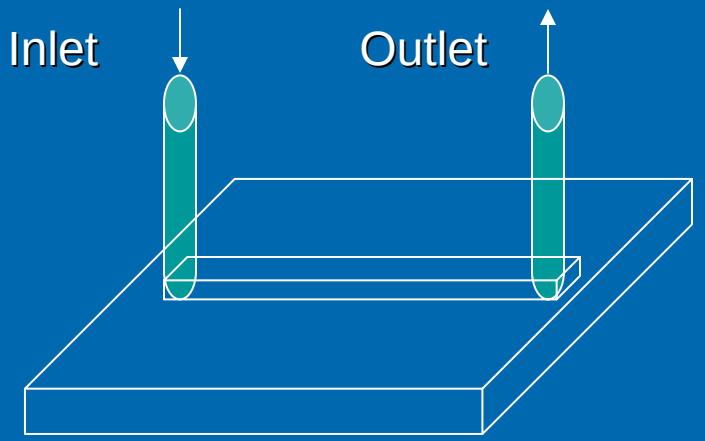
Fabrication of a Channel Biosensor

Photolithography



Reference and Enzyme electrode fabrication





Microfluidic Channel using PDMS

ES- Enzyme Surface

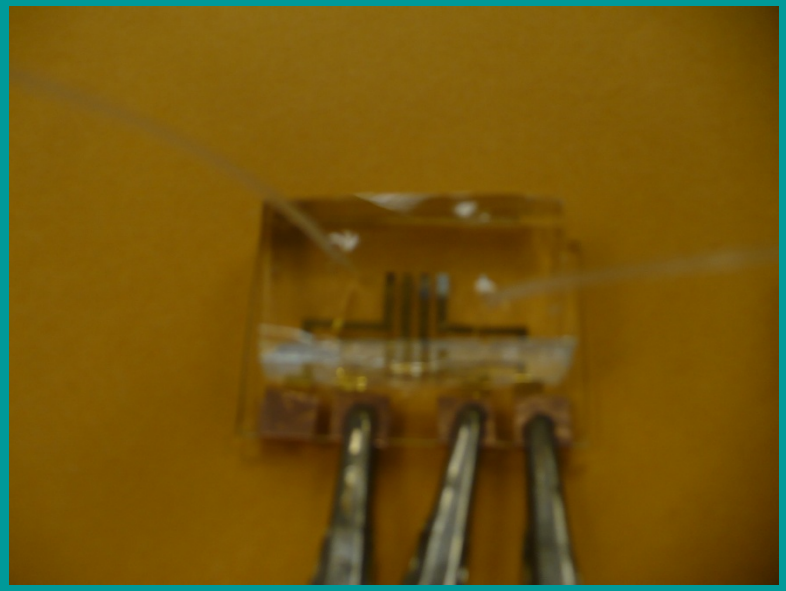
WE- Working Electrode

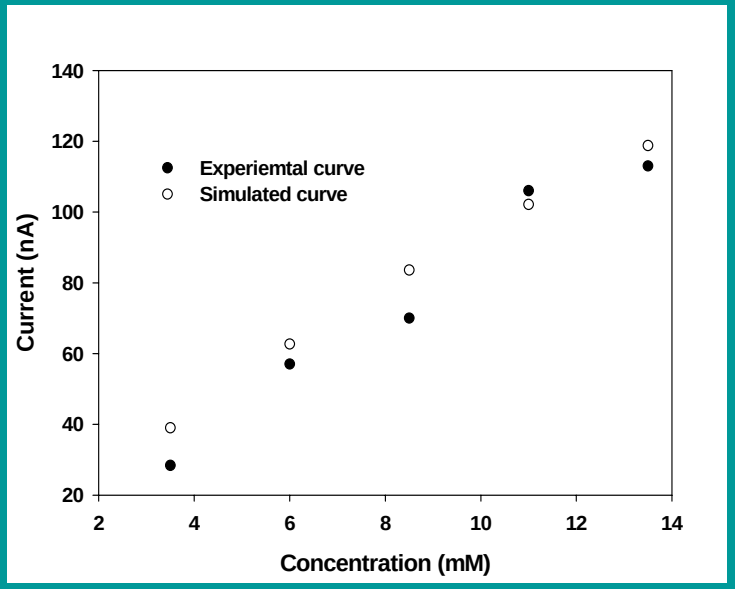
RE- Reference Electrode

CE- Counter Electrode

Results and Discussion

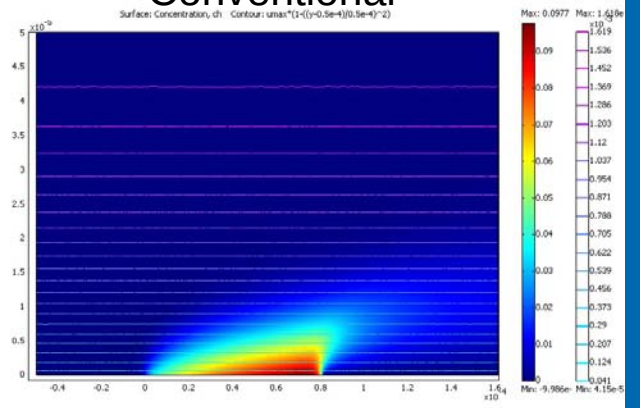
Model Validation



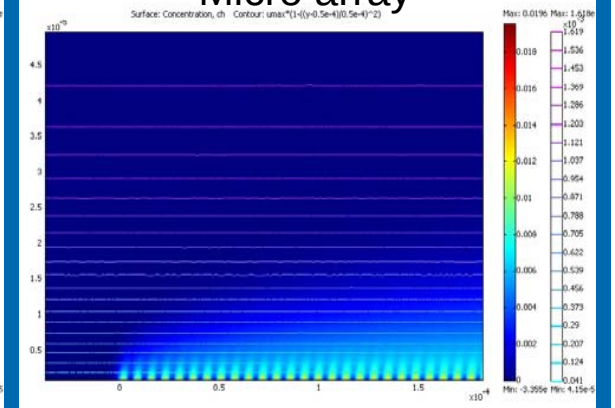


Concentration Distribution

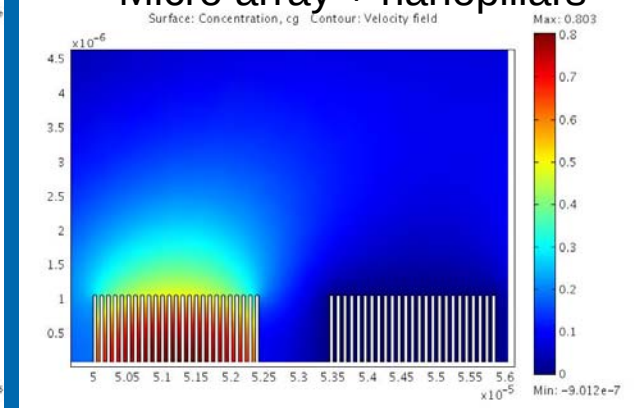
Conventional



Micro array



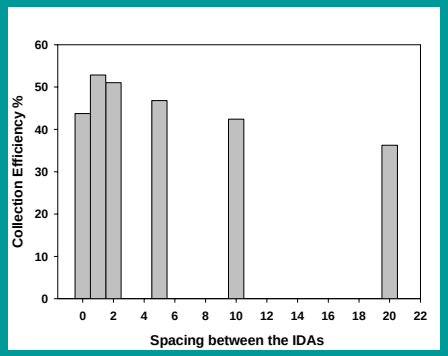
Micro array + nanopillars

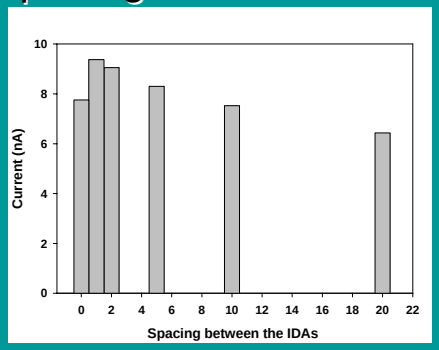


- Simulation shows higher amount of hydrogen peroxide diffusion into the bulk at the conventional design than the interdigitated design
- More amount of hydrogen peroxide is produced at the nanopillar arrays
- Glucose diffuses deep into the gaps of nanopillars

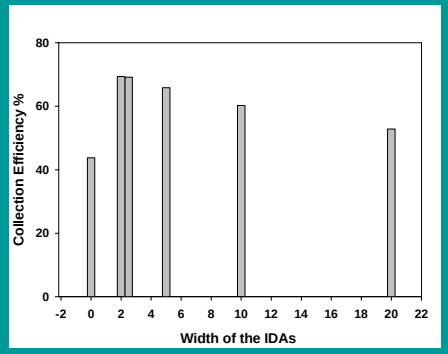
Effect of Spacing Between Interdigitated Micro Array Electrodes and Width of the Electrodes

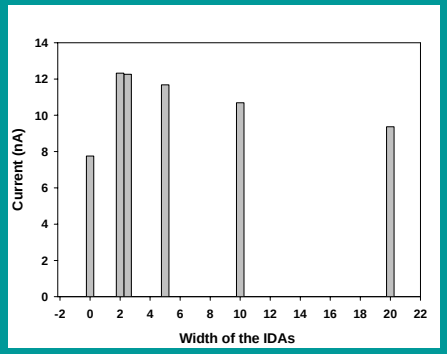
Effect of Spacing





Effect of Width

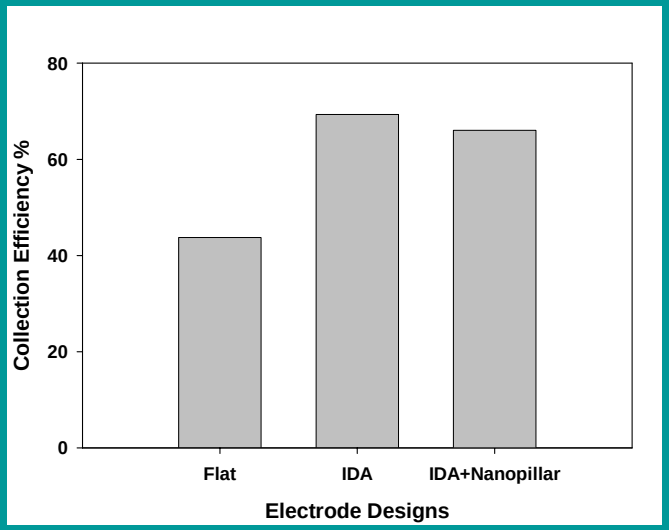


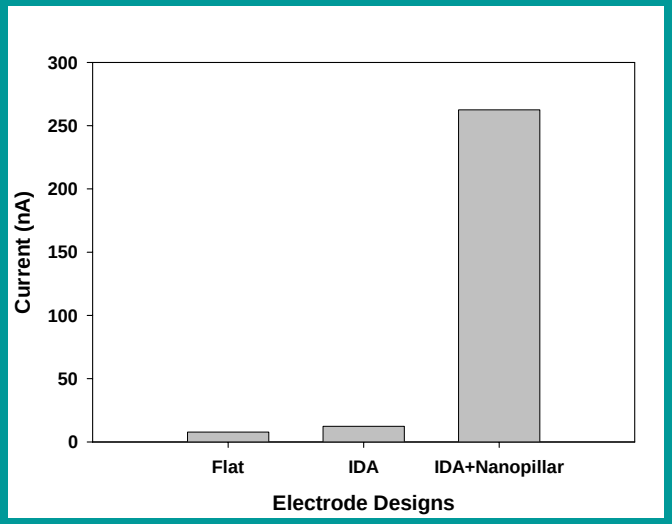


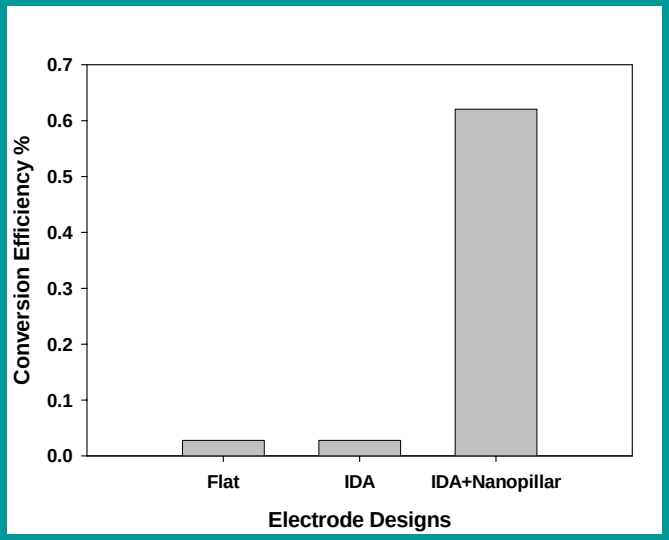
- Collection efficiency increases with the decrease in the spacing between the micro array inlaid electrodes and width of the electrode

- Maximum collection efficiency of about 65 % is obtained at a spacing of 1 µm and width of 2 µm.

Effect of Nanopillars







- Addition of nanopillars exhibited an enhancement in conversion efficiency and current response.
- Enhancement is due to the increase in enzyme loading and enhancement in mass transport at the nanostructure.

Conclusion

- The proposed design has significantly enhanced the current response of the channel biosensors.
- Presence of interdigitated micro array electrodes has increased the collection efficiency as compared with the conventional design.
- Adding nanopillars on the interdigitated micro array electrodes has increased the conversion efficiency output by two orders of magnitude as compared with the conventional design.

Acknowledgement

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